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SUCCESSFUL AUTOMATED ALLOY ATTACHMENT OF GaAs MMIC's

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TEXAS INSTRUMENTS

INTRODUCTION

Automated alloy attachment of GaAs MMIC's is presented utilizing a reflow furnace for attachment of multiple devices at one time rather than manual scrub of each monolithic separately. Reflow characteristics of a variety of solders were analyzed as well as behavior of those solders during long term temperature bake and during 1000 cycles of thermal cycling. RF and thermal impedance data was measured through 600 thermal cycles in order to verify long term electrical performance. Finally, the study addressed fractures in GaAs due to thermal expansion differences between the alloy and the GaAs MMIC itself. The main objective for the monolithic attachment study was to identify alloy materials and to develop processes which provide the following characteristics:

* reliability
* reworkability
* ease of processing and repair
* mechanical accuracy
* electrical stability

Initially a broad variety of alloys were examined both in solder pastes and in preform configuration. The monolithic utilized for the evaluation was a power chip with dimensions of 0.098" x 0.081", gold backside metallization, with both vias and air bridges (Figure 1). Reflow was conducted in a BTU furnace with dual atmosphere capability.

The test cycle was separated into two major categories. The first category included investigation of physical properties of the attachment media such as voiding, wetting, intermetallic formation, and fracture behavior. The second examined process and electrical characteristics such as processing ease and repairability, tolerance of movement during reflow, sensitivity to cumulative effects of assembly flow, and changes in electrical performance (RF and thermal impedance) during long term environmental testing.

The environmental cycle for each of the candidates included a bake of 150°C for 168 hours. Samples were baked, examined microscopically, and microsectioned for detection of gold diffusion and fractures. Another group was then subjected to thermal cycling from -55 to +125°C for 1000 cycles. Samples for each solder were

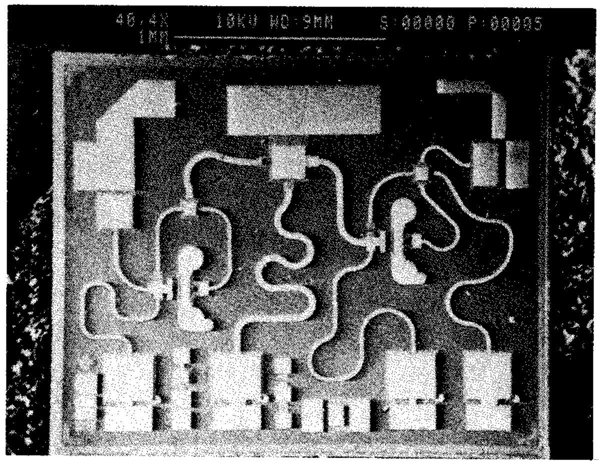

FIGURE 1. TEST DEVICE

microsectioned initially and at 200 cycle intervals. These were then analyzed with the scanning electron microscope and energy dispersive X-ray. Colored maps were developed with the X-ray so that boundaries, macrostructures within the solder joint, and intermetallic characteristics were clearly visible.

DISCUSSION

After furnace profile development, analysis of the alloy samples began with examination of wetting behavior and X-ray analysis for measurement of voiding. Wetting characteristics and voiding are listed in Table 1.

During preliminary investigation of the alloy samples, a fracturing problem was noted at the via sites on the monolithic device (Figure 2). The phenomenon was first apparent during a manual alloy scrub of a monolithic power circuit into a thermkon base package using an AuSn solder preform. Every device mounted exhibited some cracking at the via sites, and electrical yield was less than 25% at the time. Although most of the

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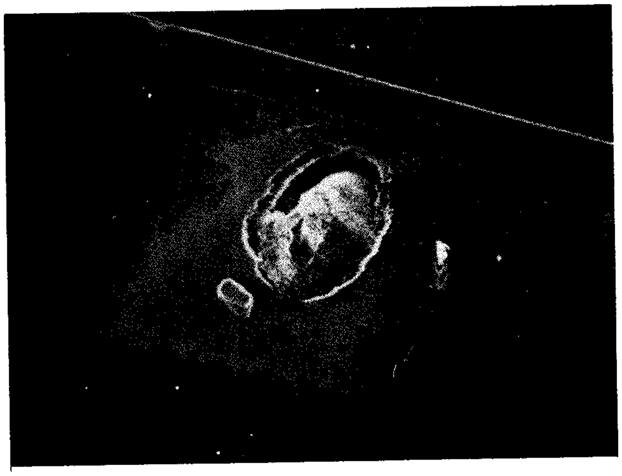

FIGURE 2. FRACTURE AT VIA STIE

cracks were of the concentric ring configuration, in some instances, cracks beginning at the via sites would propagate completely across the device or across a FET or capacitor causing electrical failure. Figure 3 is a photograph of a fracture which has propagated across a gate stripe on an electrically failed device. Troubleshooting of the power monolithic assembly clearly pointed to the fact that the frequency of the cracks could be increased with excessive heat during the scrub operation or excessive time at temperature. Since the manual operation was subject to operator variation, particularly with respect to time at temperature, a more controlled furnace reflow profile was developed to alloy these MMIC's to the package base. Although fracturing of this monolithic was not completely eliminated when utilizing AuSn solder, via cracking could be reduced to less than 5% of the devices assembled when peak temperature was lowered to the minimum heat required to reflow the alloy. Microsections, comparison of the behavior of this device with other monolithics reflowed at the same temperatures, and comparison of the frequency of cracking with alternative solder systems revealed some interesting results.

TABLE 1: Wetting and Voiding Characteristics

Solder Candidate	Paste/ Preform	Wetting	% Void Free Area
Au/Sn	preform	excellent	95%
Au/Sn	pPaste	very good	85%
Pb/Sn/Ag	preform	very good	90%
Pb/Sn/Ag	paste	excellent	85%
Pb/In/Ag	preform	good	85%
Pb/In/Ag	paste	very good	85%
Pb/In	preform	good	85%
Pb/In	paste	fair	85%

Fractures at the via could be completely eliminated by utilization of a pliable solder such as those available in the indium-based systems. Unfortunately, due to the high oxidation potential of these alloys, repair work is difficult and usually results in a greater level of voiding on the repaired assembly than achievable with AuSn. Increased voiding is particularly deleterious to the electrical yield on a power monolithic assembly. Further investigation demonstrated that the fracture phenomenon was due to a thermal expansion mismatch between the GaAs and the solder. Capillary action caused the vias to fill with solder and, in some cases, caused the alloy to pierce through the top surface of the device. It was found that the problem could be eliminated by limiting the amount of solder which penetrates the via. A critical process window must be developed for each alloy to minimize the amount of solder filling the via while at the same time maintaining sufficient backside solder coverage to provide good thermal dissipation.

Initial candidates were narrowed to four, and an environmental bake for 168 hours at 150°C was completed. For the bake operation, four carrier plates per alloy, with six devices on each carrier plate, were reflowed, baked, and microsectioned. Environmental testing also encompassed thermal cycling. For these tests, 12 carrier plates per alloy were mounted with four MMIC's on each. Thermal cycling continued for a maximum of 1000 cycles with two carrier plates for each solder sample pulled and microsectioned initially, and at 200 cycle interval steps.

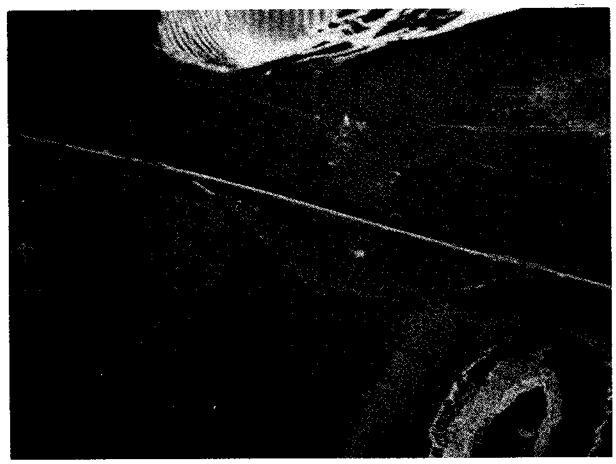

FIGURE 3. PROPAGATION ACROSS A GATE STRIPE

The solder exhibiting the greatest change, due to thermal cycling, was Pb/Sn/Ag (90/5/5). After the initial reflow process, little gold plating remained either on the carrier plate or on the underside of the MMIC. The gold had diffused into the solder and segregated into separate nuclei after the thermal cycling (Figure 4). Pb/In/Ag (92.5/5/2.5) behaved in a similar fashion

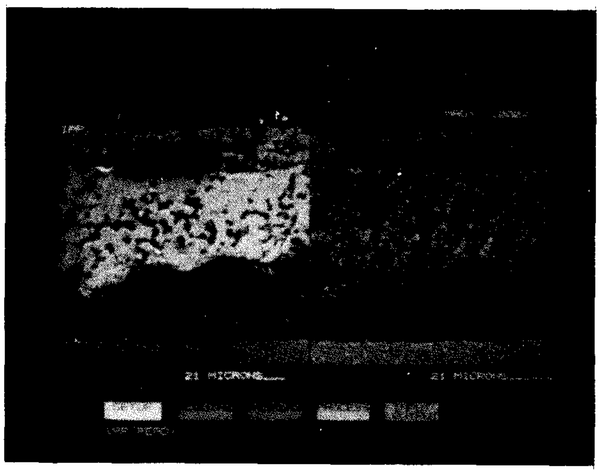

FIGURE 4. Pb/Sn/Ag (90/5/5) GOLD DIFFUSED INTO SOLDER AND SEGREGATED INTO NUCLEI

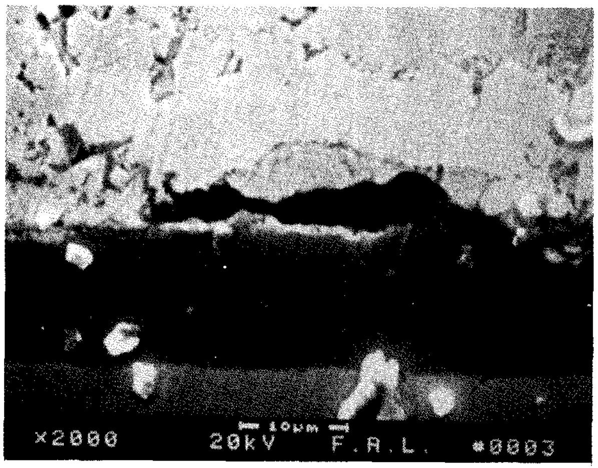

FIGURE 5. Pb/In/Ag FRACTURES IN THE GOLD DEPLETED REGION

with most of the gold diffusion occurring at initial reflow. Fractures began to occur at the gold/indium intermetallic boundaries within the solder joint and at the gold depleted regions of both the carrier plate and the MMIC (Figure 5).

Two candidates remained viable for MMIC attachment: Pb/In (75/25) and Au/Sn (80/20). Both exhibited little or no gold diffusion and no fractures through 1000 cycles of thermal cycling.

With the final candidates, 16 amplifiers were assembled and tested. Eight were tested for RF characteristics and eight for electrical thermal impedance characteristics. These were measured initially at 200, 400, and 600 cycles (thermal cycling from -55 to +125°C). No changes in RF performance or thermal impedance were experienced with either of the alloy samples.

CONCLUSIONS

In conclusion, an automated alloy attachment process was developed for GaAs MMIC's. The alloy materials analyzed included both pastes and preforms. A comprehensive reliability evaluation demonstrated that even the mildest flux was not viable for application with GaAs MMIC's, and silver bearing solders resulted in significant gold diffusion and fracturing during thermal cycling. Two viable candidates emerged from the test cycle, Au/Sn (80/20) and Pb/In (75/25). When examined electrically, amplifiers assembled with these candidates exhibited no change in thermal impedance or RF characteristics through 600 thermal cycles.